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ESTIMATING THE TRUE CONSOLIDATION BEHAVIOR OF CLAY FROM LABORATORY TEST RESULTS

by John H. Schmertmann, J.M. ASCE

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ESTIMATING THE TRUE CONSOLIDATION BEHAVIOR OF CLAY FROM LABORATORY TEST RESULTS

John H. Schmertmann*
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INTRODUCTION

The purpose of this paper is to present quantitative methods whereby laboratory consolidation test results, modified by the inevitable partial sample disturbance, may be corrected for the effects of this disturbance and thus more reasonably predict the true behavior of the clay in the field. The writer believes that knowledge of the effects of sample disturbance has advanced to the point where attempts at quantitative corrections are justified.

Estimating the true behavior of clay deposits in the field involves two soil mechanics problems. The first is estimating the true physical properties of the soil. The second is determining the applicability of the method of analysis to the given problem. This paper deals primarily with the former. However, it can be expected that more realistic laboratory results will lead to a better understanding of the significance of comparisons between computed and observed field performance.

The correction of consolidation test results is investigated using the following general approach:

1. What is the basic behavior of the test data?
2. How is this behavior modified by sample disturbance?
3. What is the pattern of such modifications?
4. The use of any such patterns as a basis for estimating, by extrapolation, the completely undisturbed conditions.
5. An example of results obtained by the use of the suggested methods.

Included is some discussion of the preconsolidation stress, the computation of recompression settlements, and the effects of sample disturbance on the laboratory time curves.

The data and methods introduced in this paper are limited in application to natural cohesive soils. The laboratory testing and job experience background for this study is limited to saturated organic and inorganic sedimentary clay deposits and to clays deposited as a result of glacial action. Because of a lack of sufficient data, the writer excludes partially saturated and residual clays from this work.

TERMINOLOGY

In this paper the term "consolidation test" refers to either the fixed or floating ring standard one-dimensional laboratory test. The "pressure-void

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ratio diagram" refers to the conventional semi-log method of indicating the results of the consolidation test.

All new terminology introduced by the writer will be explained at the time of presentation.

Basic Consolidation Behavior

Laboratory

The basic laboratory behavior of a clay consolidating under the influence of vertical stresses higher than previously experienced by the sample is to have its void ratio (or water content) steadily reduced with increased intergranular soil pressures. Neglecting long time secondary consolidation it may be said that for each new effective stress there is a new equilibrium void ratio. When a number of these points are plotted on a semi-log plot, the resulting very flat curve is known as the virgin consolidation slope.

In order to demonstrate that the position of the virgin slope is unique for a given soil (with constant disturbance) the reader is referred to Figure 1. These six excellent consolidation tests were performed on samples obtained from a single boring and distributed throughout the uniform lower 1/2 of a 60' bed of recently deposited organic silty clay. The range of 3.08 to 2.24 in initial void ratio is the result of varying degrees of consolidation under a recent fill. Laboratory results similar to those noted on Figure 1 have been obtained from other uniform soil formations. An excellent example is some consolidation test data on Mexico City Clay obtained by Dr. P. C. Rutledge.(1)

Field

Let us now investigate the basic behavior of a clay as it consolidates geologically in nature. In order to do this effectively it is necessary that one investigate only proven uniform clay deposits with a known stress history. Because of the foresight of Mr. James D. Parsons*, the writer has been fortunate enough to have access to a number of soil investigations, adequately documented by extensive laboratory data, which directly or indirectly indicate the manner of geologic consolidation. The following is a detailed presentation of the most direct of these investigations.

Figure 2 presents the soil laboratory data on a bed of river deposited organic silty clay. This river formation is finely layered with alternate layers of organic silty clay and silty fine sand. The sand layers ranged in thickness from a thin sifting of sand to a maximum of 1/8". The thin sand layers constitute a minor fraction of the entire formation. The laboratory samples were taken with a 3" diameter, thin walled, fixed piston type sampler and were distributed throughout 12 borings and 5 dredge positions across the 4000' river width. To permit correlation, all data are plotted in terms of depth below river bottom.

Referring to Figure 2, (a) and (b) indicate the Atterberg limit and specific gravity laboratory test results. These data are presented to show the overall uniformity of the river deposit. Figure 2 (c) is a plot of the water content data in which each point represents the average of a minimum of 2 or 3 water content determinations. On this plot is shown the average water content profile as determined by the writer on the basis of the best curve fitting through block averages of the detailed data. The sharp curvature given to the upper

*Associate Partner; Moran, Proctor, Mueser & Rutledge.

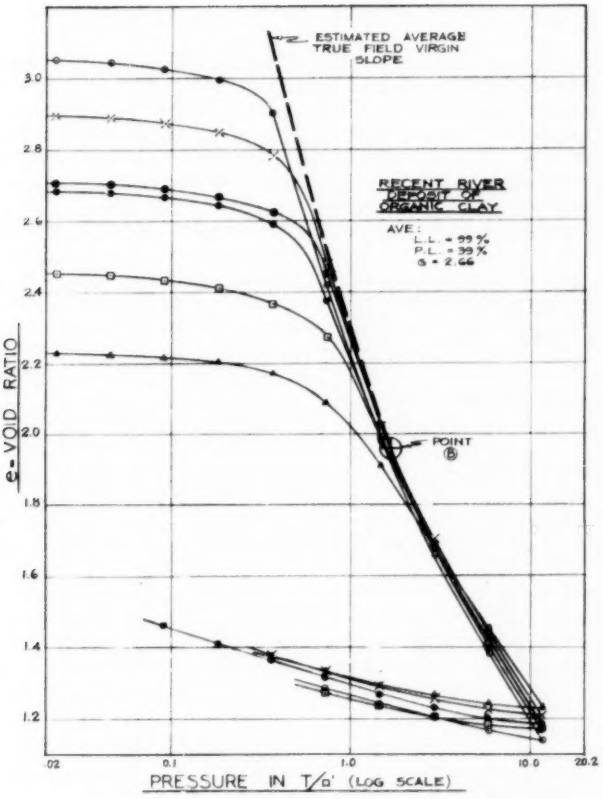


FIG. 1 - EXAMPLE OF UNIQUE POSITION OF LABORATORY VIRGIN SLOPE

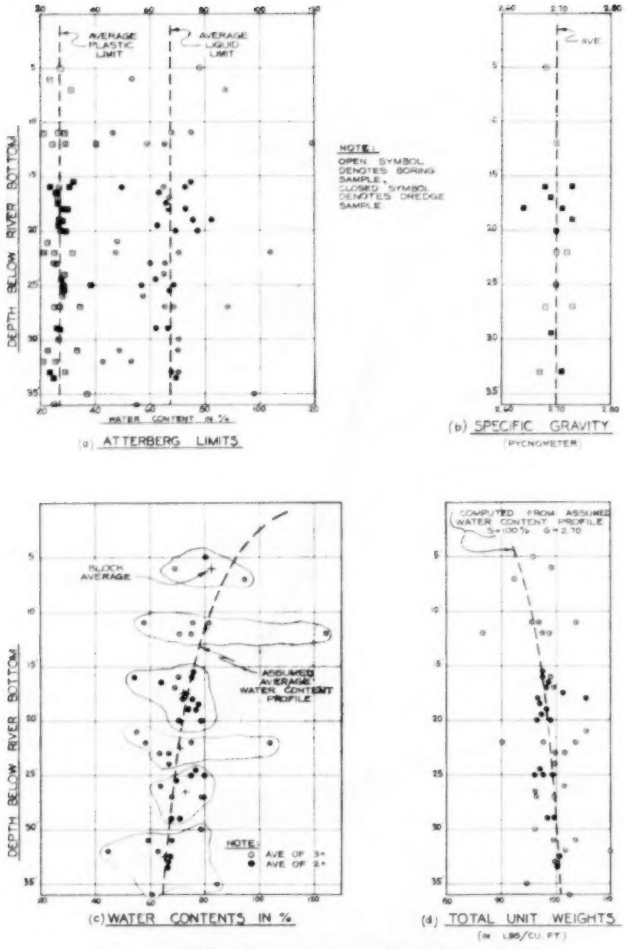


FIG. 2 - LABORATORY TEST DATA FROM RIVER DEPOSITED ORGANIC SILTY CLAY

portion of the assumed water content profile is based on the fact that the upper 5' of this formation was reported to be in a "semi-fluid" condition. It is probable that the semi-fluid state results from any disturbance of this very soft clay because its water content is very much higher than the liquid limit. Figure 2 (d) shows total unit weights as determined by weight and volume determinations made on the entire sample before it was removed from the sampler tube, together with a unit weight profile computed from the assumed water content profile. The computed profile checks well with the observed data. The numerous thin sand seams are believed to be at least partially responsible for the scatter of the data on Figure 2.

To summarize, the data presented indicate an essentially uniform soil formation which shows an average consistent decrease in water content with depth.

The next point to consider is the geologic stress history of the formation. This river deposit is presently under an average of 35 feet of water and is believed never to have had its surface above water. Thus there would be no preconsolidation by surface drying, as is often found in otherwise uniform soil deposits. This conclusion, plus the belief that the overburden never significantly exceeded that presently existing, is strongly supported by the observation of the very soft consistency of the upper 5' of the deposit. The many thin fine sand layers noted throughout this formation make it probable that the soil is normally consolidated.

If one assumes normal consolidation it is now possible to simply compute the pressure-void ratio plot for the geologic consolidation of this soil formation. Overburden stresses can be computed directly from the computed average unit weight profile. Void ratio can be computed from the average water content profile. Such computations have been made by the writer for 5' increments of depth below river bottom. A semi-log plot of the results is shown in Figure 3. Also shown is a laboratory consolidation test on a sample taken at a 22' depth.

Referring to Figure 3, the computed geologic consolidation is along the typical flat curve observed in laboratory virgin slopes (see Figure 1). The computed geologic virgin slope also checks well with the observed virgin slope from a laboratory consolidation test on a partially disturbed sample of the same soil.

The above analysis, plus several others which include Detroit and Chicago Clay formations but required a more indirect approach, have consistently led the writer to the conclusion that a natural clay consolidates geologically along a similar, if not identical, virgin slope as that which would be obtained from a completely undisturbed laboratory consolidation test.

Effects of Sample Disturbance

Dr. Rutledge summarizes the general effects of sample disturbance on the laboratory consolidation test as follows:[1]

> "(1) It decreases the void ratio at which the soil will carry any given vertical stress:
>
> (2) It obscures the previous stress history of the soil and its preconsolidation load: and
>
> (3) The straight-line portion of the remolded compression curve is displaced downward from the laboratory virgin compression curve, and its slope, or the rate of decrease in void ratio with increasing stress, is less.

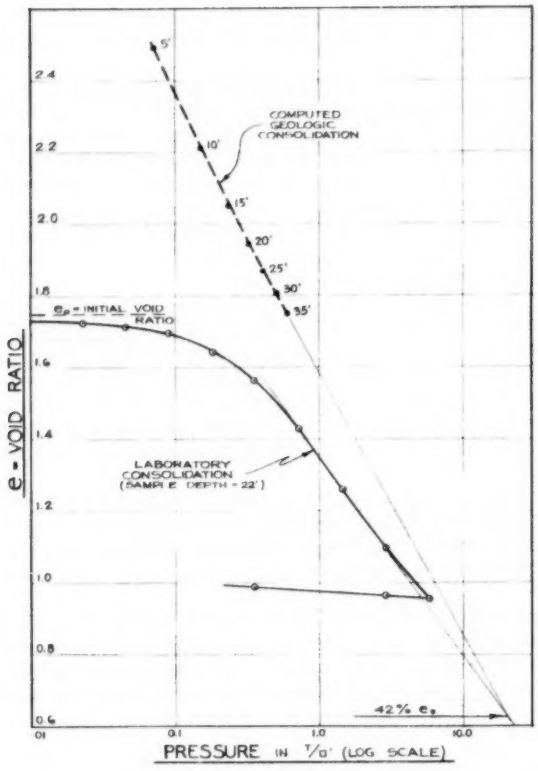


FIG. 3 - COMPARISON OF LABORATORY AND GEOLOGIC CONSOLIDATION

These results show definitely the effects of sample disturbance over the range from the best undisturbed samples which have been obtained for laboratory test to complete remolding. Any intermediate degree of disturbance must result in a compression curve which falls between the curves that would be obtained for the same soil in these two known limiting conditions".

Figure 4 presents data from 2 glacial and 2 organic soils showing typical consolidation test results from the best obtainable "undisturbed" samples, and on other completely and partially remolded samples of the same soil. Figure 5 shows data obtained by T. Van Zelst which summarizes the results of a phase of his Master's thesis dealing with the effects of varying degrees of disturbance on the consolidation test results.(2) Different degrees of disturbance were obtained by using a constant diameter ring and varying the height of the sample, thereby varying the percent of total volume disturbed by sample trimming. The data on figures 4 and 5 offer additional evidence of the validity of Rutledge's conclusions. However, these data also permit some additional observations.

Straight-line extensions of the initial virgin slopes of consolidation tests with varying degrees of disturbance intersect within a narrow void ratio range. The term "initial virgin slope" means the slope of a straight line drawn through the first two laboratory test points which fall on the virgin portion of the pressure-void ratio diagram.

The data on figures 3 and 5 indicate that the intersection of the true initial virgin slope with the initial virgin slopes of laboratory consolidation tests ranges from 40 to 46% of the initial sample void ratio. The data on figures 4 and 14 indicate that the intersection range for "undisturbed" and more disturbed samples is between 37 and 60%. If one excludes the very unusual soil shown in figure 4 (a), and the pile disturbed sample in 4(b), the latter intersection range becomes 37 to 46%.

On the limited basis of the above and similar data, the writer believes that an intersection point at 42% of the initial void ratio would be a good estimate for most clays.

Under each set of comparative consolidation tests the writer has plotted a "void ratio reduction pattern". This is simply a curve showing the pattern of the void ratio reduction of the disturbed test when it is compared to the "undisturbed" test. With respect to the best consolidation curve, the void ratio reduction for a more disturbed test increases from a small value at low stresses to a maximum value at or near the preconsolidation stress, and then decreases again as one moves along the virgin slope. A useful observation is an apparent tendency toward symmetry about the maximum value. The data on Fig. 5 indicate that the same pattern may exist between the clay in the field and the laboratory sample.

Finally, disturbance does not appear to affect the magnitude of the rebound slope. Examination of Van Zelst's thesis and numerous other test data confirms this observation.

The Geologic Rebound of a Preconsolidated Clay

Laboratory investigations show that it is a common occurrence to find clays that have been subjected to pressures in their geologic history which are greater than those presently existing in the form of overburden. During the process of stress release from this preconsolidation stress to that now existing, the soil must have swelled, or rebounded. The question is what is the magnitude of this rebound slope?

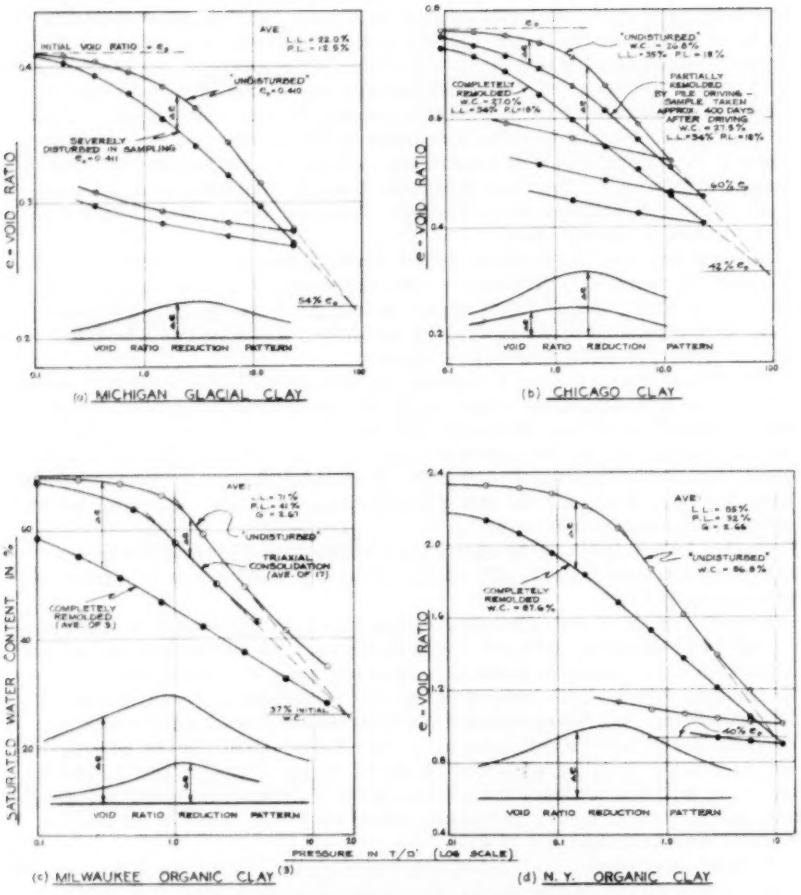


FIG. 4 - COMPARISONS OF "UNDISTURBED" AND DISTURBED CONSOLIDATION TESTS

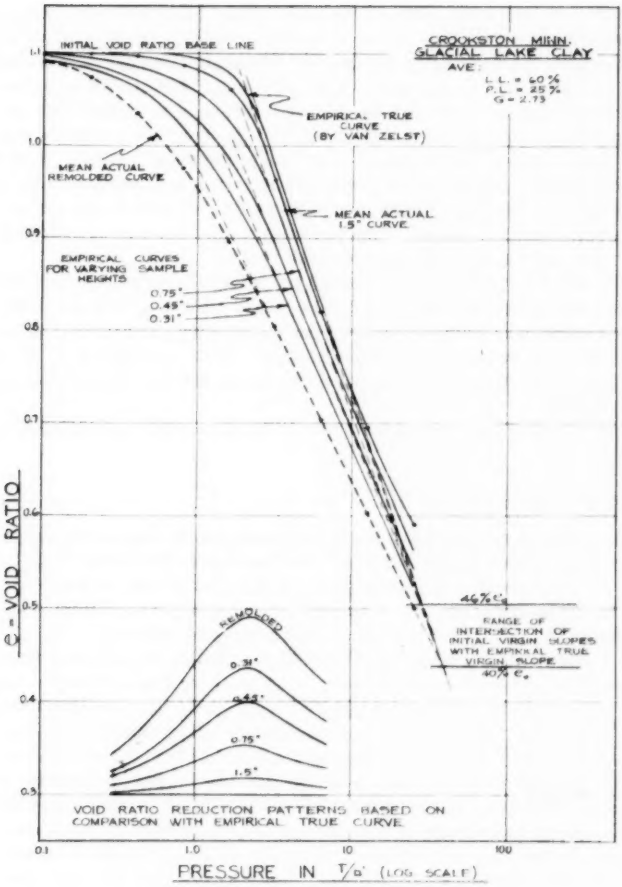


FIG. 5 - EFFECT OF SAMPLE DISTURBANCE ON THE e - LOG P DIAGRAM

Let us imagine a laboratory consolidation test on a highly preconsolidated clay. What would be the shape of the recompression portion of the test curve? Long rebounds, and subsequent recompressions of laboratory samples show a shallow hysteresis loop in which the recompression is parallel to, and at a slightly higher void ratio than the rebound. If a similar rebound occurred geologically in the field, one would therefore also expect the field recompression to be approximately parallel to the geologic rebound and form a shallow loop with this rebound.

The reader is now referred to Figure 6. This Figure shows typical laboratory consolidation test results on a variety of highly preconsolidated clays. These tests were performed in the Moran, Proctor, Mueser & Rutledge laboratory on samples 2.5" in diameter and 1.0" high. Any swelling under light loads was immediately arrested by the application of the next load increment. The 3-slope character of such tests is shown by first the constant void ratio line, then the recompression slope, and finally the virgin slope. For each test the writer has indicated the computed existing overburden, and has constructed a dashed line parallel to the laboratory rebound to aid comparison with the recompression slope. The recompression curves are approximately parallel to the laboratory rebound slopes.

Since the field recompression should be parallel to the geologic rebound, and is observed to be parallel to the laboratory rebound, it is probable that the geologic rebound is approximately parallel to the observed laboratory rebound which concludes a consolidation test. This conclusion is in accord with the previously discussed similarity between laboratory results and geologic behavior.

As shown previously, rebound slopes do not appear to be affected by sample disturbance.

The Preconsolidation Stress

Determination of the preconsolidation stress is an important phase of estimating the true consolidation behavior of the clay in the field. Unfortunately, distortion of the previous stress history of the soil is one of the most serious results of sample disturbance. However, there are several important aids one can use in the determination of preconsolidation values.

Figure 7 illustrates a method which can be employed to determine a minimum possible preconsolidation stress. The method was originally taught by Dr. P. C. Rutledge and has been slightly modified by the writer. Referring to Figure 7, point E represents the presently existing overburden and void ratio. Line E-P' represents the geologic rebound constructed parallel to the lab rebound through point E. One now extends the laboratory initial virgin slope until it intersects either the initial void ratio or geologic rebound lines at point m. From knowledge of the effects of sample disturbance, one knows that the true virgin slope must lie to the right of the laboratory slope. Therefore point m must always be at a lower stress value than the true preconsolidation value P.

If it can be stated with a reasonable degree of certainty that the preconsolidation stress cannot be below a certain value, one has established a lower limit which may have important engineering significance. If this lower limit falls higher than the overburden pressure known to be effective at the elevation of the sample, one is reasonably certain that some, if not all, of the consolidation settlement will be recompression. On the other hand, if the lower limit consistently falls below the computed overburden stress, the analysist then has grounds for suspecting a normally consolidated soil, and on rare occasions, an under-consolidated soil.

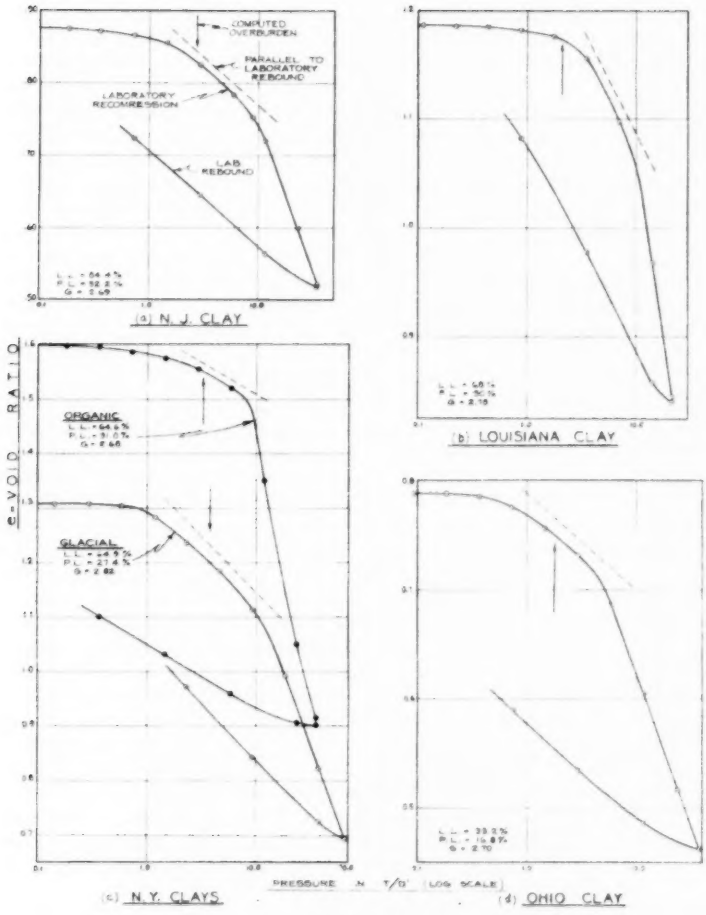


FIG. 6 - COMPARISONS OF LABORATORY RECOMPRESSION & REBOUND SLOPES

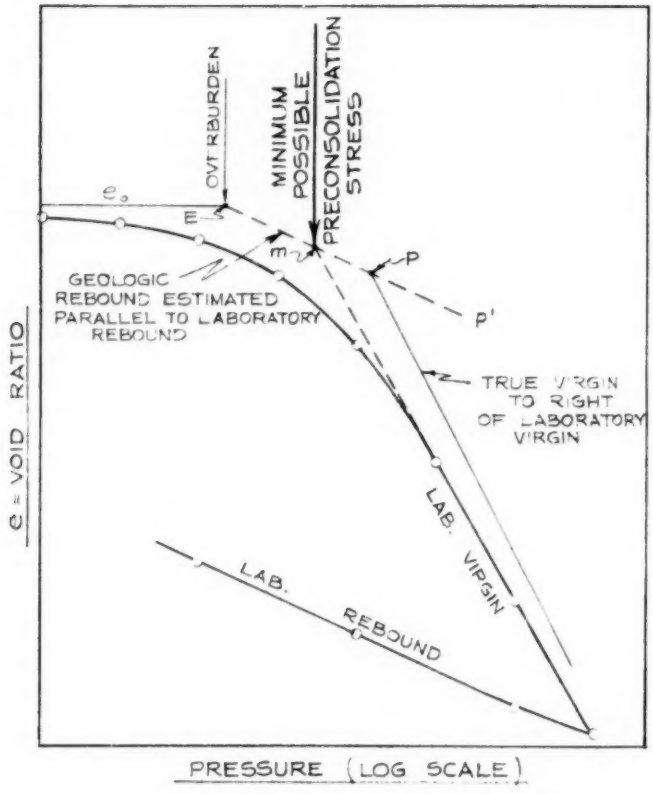


FIG. 7 - DETERMINATION OF MINIMUM POSSIBLE PRECONSOLIDATION STRESS

While it is rare to find an entire clay layer that is uniform, it is not too uncommon to find clay formations with a portion of their thickness exhibiting uniform consolidation properties. Uniformity can be either demonstrated directly by consolidation tests, or indirectly by classification tests. If such a situation can be found, the water content profile through this portion of the formation can be utilized to estimate true preconsolidation values.

An example of such an estimate was the data presented in Figures 2 and 3 in which a study of the water content profile indicated normal consolidation. For another example the reader is referred to Figure 8. In this case the lower 1/2 of a 60 ft. organic clay deposit was demonstrated to have uniform consolidation properties by the consolidation tests presented in Figure 1. Figure 8(a) shows the water content data and assumed profile for this portion of the formation. In this analysis a direct tie-in between water content and effective stress was possible. This was so because this was a case of double drainage consolidation under a recent fill and the effective stress at the bottom of the compressible layer could be computed. The effective stress-void ratio computation for point B is shown by the large circled cross in Figure 1. This represents a point on the true average virgin slope of this soil. The heavy dashed line on Figure 1, which passes through point B, is an estimate of the average true field virgin slope over the void ratio range shown. By converting the water content profile to void ratio, and using the estimated true virgin slope, it is now possible to compute the effective stress profile at the time of sampling.

The results of this computation are shown on Figure 8(b) in relation to total effective plus excess hydrostatic stresses existing before and after the fill was placed. Once the preconsolidation distribution was determined for the lower 1/2 of the formation it was simple to estimate it for the upper 1/2. Settlement computations using the above complete distribution gave a close agreement with what was actually observed since the fill was placed. In cases where no direct relation between water content and effective stress can be determined, trial and error procedures must be used until the water content profile checks an assumed preconsolidation profile.

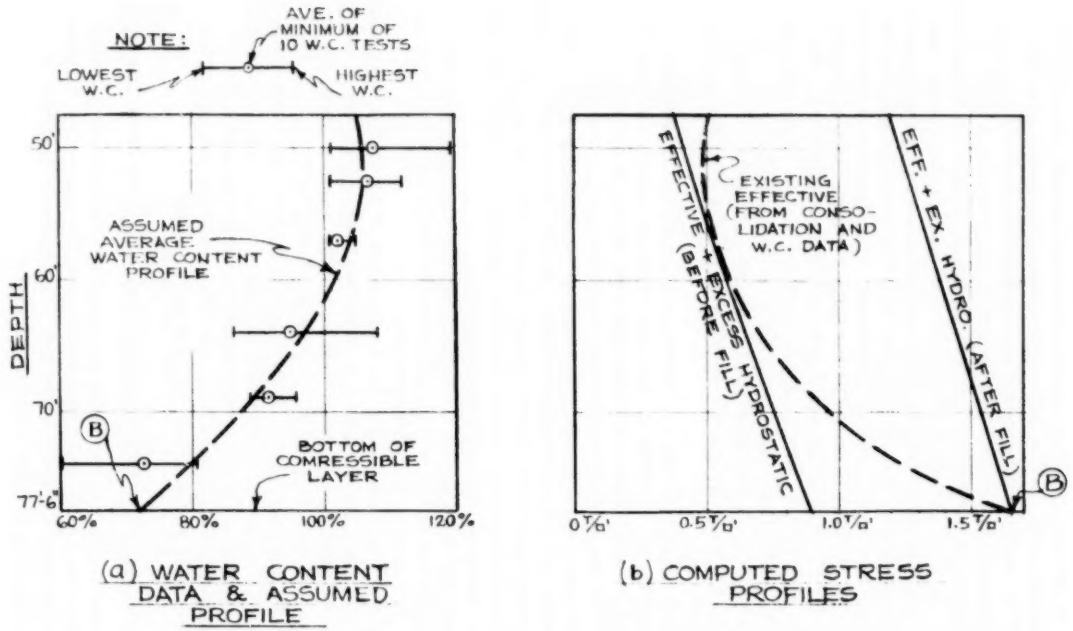
Another method that permits the successful application of water content data to the determination of the preconsolidation profile is the water content-plasticity ratio. For details see Reference (4).

The writer believes that ultimately the best method of directly determining the preconsolidation value will be based on a thorough understanding of the nature of the distortion of the pressure-void ratio diagram due to sample disturbance. The void ratio reduction patterns presented in Figures 4 and 5 may be a step in the right direction. At present the writer uses these patterns by choosing various possible preconsolidation values, reconstructing the estimated true consolidation test for each chosen value, and then picking the highest value which gives a symmetrical void ratio reduction pattern. The results obtained thus far are encouraging, but inconclusive.

Reconstruction and Use of the Estimated True Pressure-Void Ratio Diagram

The writer will now attempt to utilize the previous discussions in order to reconstruct the estimated true consolidation pressure-void ratio diagram. Starting with the laboratory consolidation test, the reader is referred to Figure 9 for the following step by step procedure:

1. Plot point E, which represents effective stress and void ratio now existing in the field at the sample location. Barring unusual soil stress and sample



(a) WATER CONTENT DATA & ASSUMED PROFILE

(b) COMPUTED STRESS PROFILES

FIG. 8- EXAMPLE OF DETERMINATION OF PRECONSOLIDATION FROM WATER CONTENT PROFILE

storage conditions, the initial stress can be taken as the computed overburden pressure p_o, and the initial void ratio as the computed saturated initial void ratio, e_o, of the consolidation test sample.

2. Because E represents the initial conditions for field compression, a perfect consolidation test must start as a constant initial void ratio line to point E.

3. Determine the preconsolidation stress value by the best method available. Construct a light constant stress line, x - x, at this stress value.

4. Construct the geologic rebound, parallel to the laboratory rebound, through point E and intersecting line x - x at the preconsolidation point P.

5. Extend the initial laboratory virgin slope as a straight line until it intersects the 42% e_o line at point i. Then construct the line i-P. This line represents the initial position and slope of the estimated true virgin curve.

6. Estimate a recompression curve for the geologic rebound line E-P. This curve probably merges with the estimated true initial virgin slope in such a manner that the graphical construction at the point of sharpest curvature will yield the preconsolidation point P.(5)

The dashed line on Figure 9 indicates the final reconstruction of the estimated true field pressure-void ratio diagram.

In the event that it is determined that the clay is not preconsolidated, the construction of the geologic rebound and estimation of a recompression curve are eliminated. The effective stress is either the overburden or some lower value on the initial void ratio line. The estimated true initial virgin slope is still determined in the manner outlined in step 5.

The reconstructed true pressure-void ratio diagram can now be used directly for settlement computations. As shown on Figure 9, a stress increase of from p_o to p_1 would result in a void ratio reduction along the recompression portion of the consolidation test. Because the amount of loop between the geologic rebound and the recompression curve is a matter of judgment, the writer has indicated two possible recompression void ratio changes. The most probable is based on the estimated recompression curve. The maximum assumes no loop, and therefore a recompression back along the geologic rebound.

If the stress increase is from p_o to p_2 both recompression and virgin consolidation would occur. The void ratio reduction for this load increase is indicated, and is independent of any assumed recompression curve.

Should there be a net decrease in load from p_o to p_3 the soil would continue to rebound along the established geologic rebound slope and yield the void ratio increase shown.

A Settlement Analysis

In order to give the previously developed theoretical concepts a definite practical significance, the writer will now follow through an interesting settlement analysis which permitted the use of many of the concepts introduced in this paper.

A company was proposing to build additional storage facilities adjacent to a rigid 8-bin silo structure which had been constructed in 1926. In order to check the accuracy with which one could compute the settlement of the new structure, the writer performed settlement analyses for three locations on the 1926 structure, for which load and settlement records had been kept. Very uniform soil conditions over the entire site area permitted such a procedure. The following presents the most significant phases of this settlement analysis:

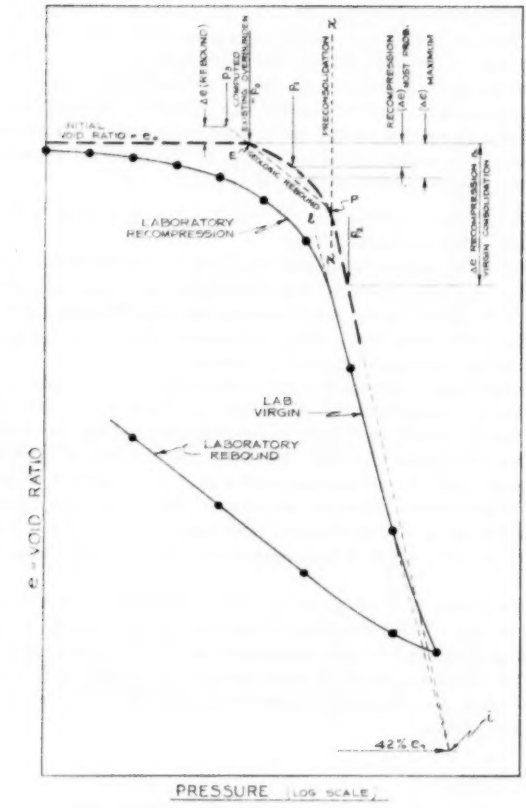


FIG. 9 - RECONSTRUCTION OF TRUE 1-DEMENSIONAL CONSOLIDATION BEHAVIOR

After a series of preliminary borings established the uniformity of the subsoil conditions, a single undisturbed sample boring was made in the area of the proposed structure. A schematic log for this boring is indicated on the left side of Figure 10. In this instance the compressible layer causing settlements (shown shaded) was a medium to hard inorganic, river deposited, gray-green clay extending from elevation -50 to -139. This layer contained occasional thin silt lenses and pockets, and three silt layers which are indicated on the profile. Numerous classification and water content tests were performed on undisturbed samples from this compressible layer. On the basis of these tests plus the boring log information, five settlement computation layers were established, and a consolidation test was performed on an undisturbed sample from each layer in order to determine the consolidation characteristics of each layer and the overall preconsolidation profile. The laboratory consolidation test results are presented in Figure 11. The elevations of the consolidation test samples, minimum and most probable preconsolidation estimates, and the estimated most probable preconsolidation profile are shown on Figure 10.

In this analysis the writer chose to use the previously discussed void ratio reduction pattern method of estimating the most probable preconsolidation values. An example is shown on Figure 12. On this figure, various possible preconsolidation values were tried and a reconstructed true curve was made for each trial value. The resulting void ratio reduction patterns for three trials are indicated, as well as the one chosen.

On the upper right hand corner of Figure 10 is shown a plan of the foundation mat of the silo structure which includes the locations of the three settlement points. The recorded average live plus computed dead load over the area of the foundation mat was 2.23 T/sq. ft. This load was transmitted through wood piles into a 19' bearing layer of sand whose top was at elevation -3'. The piles almost penetrate this sand layer. Figure 10 shows the assumption used to account for the load distributing action of this bearing layer. Using this assumption the average stress increase at the top of the clay formation was 1.90 T/sq. ft. The Boussinesq elastic stress distribution charts for rectangular areas were then used to estimate the stress increase profile under the three settlement points.[6] These stress increases are in addition to the computed existing overburden pressure, and are so plotted on Figure 10.

The average void ratio for each computational layer was determined from the water content data, and the average initial and preconsolidation stresses were determined from the overburden and preconsolidation stress profiles. These values are indicated on the log in Figure 10. These values, together with the reconstructed virgin slope and rebound magnitudes from the appropriate consolidation test, were then used to reconstruct the average true consolidation pressure-void ratio diagram for the entire computational layer. An example of this reconstruction for layer 2 is shown on Figure 12.

The analyst has now reconstructed five average true consolidation tests, each one representative of a certain portion of the total compressible layer. The next step is to indicate the appropriate average total stress under settlement points A, B, and C on each of the average true pressure-void ratio diagrams. As was shown on Fig. 9, the void ratio reduction can then be determined directly from the pressure-void ratio diagrams. The void ratio reduction, Δe, can then be converted into settlement by the familiar formula

$$\Delta H = H_o\left(\frac{\Delta e}{1 + e_o}\right).$$

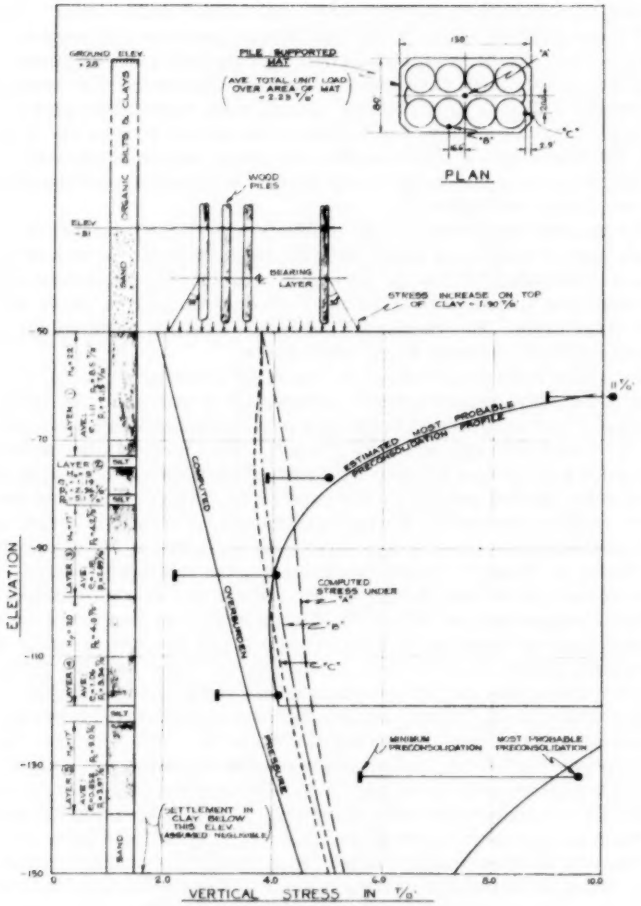


FIG. 10 - STRESS PROFILES UNDER SETTLEMENT POINTS

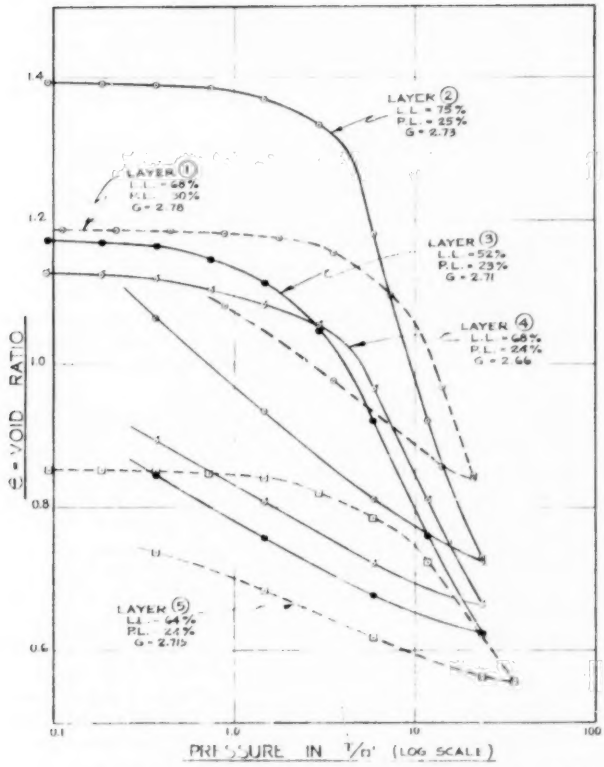


FIG. 11 - LABORATORY CONSOLIDATION TEST DATA USED IN SETTLEMENT ANALYSIS

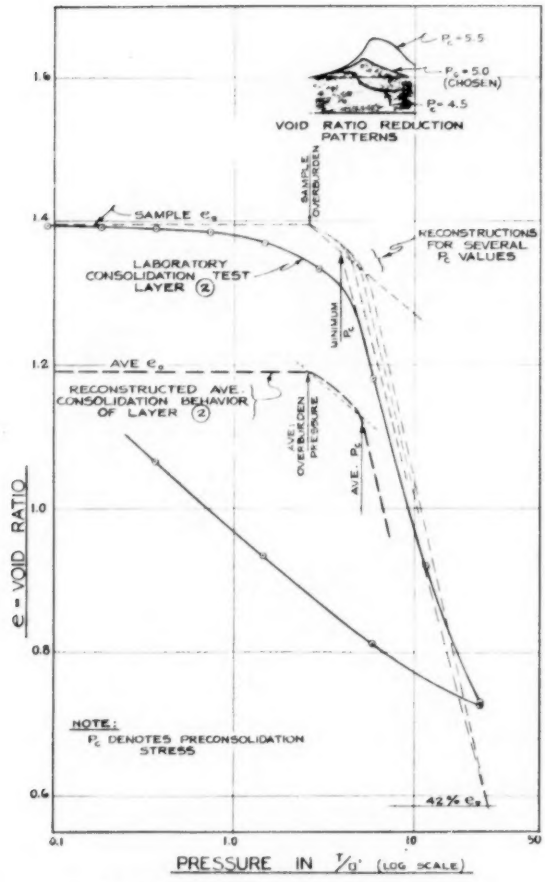


FIG. 12 - TYPICAL UTILIZATION OF LABORATORY PRESSURE - VOID RATIO DIAGRAM

The following Table I indicates the results of the settlement computations for each layer, whether the settlements are recompression or both recompression and virgin, and finally the observed settlement of the rigid structure. Because the records indicate that settlements are now complete, all computations are for ultimate settlement.

Table I

COMPUTED (Flexible Structure)												Observed in field (Rigid Structure)
Settle-Pt.	Layer and Nature of Settlement*										Total	
	1	N	2	N	3	N	4	N	5	N		
A	5.0"	R	1.1"	R	3.9"	R-V	4.7"	R-V	0.8"	R	15.5"	12.3
B	4.4	R	0.8	R	1.9	R-V	3.3	R-V	0.5	R	10.9"	11.3
C	4.3	R	0.7	R	1.4	R	1.8	R-V	0.4	R	8.6"	9.9
										Ave	11.7"	11.2"

* R Denotes Recompression
R-V Denotes Recompression then Virgin

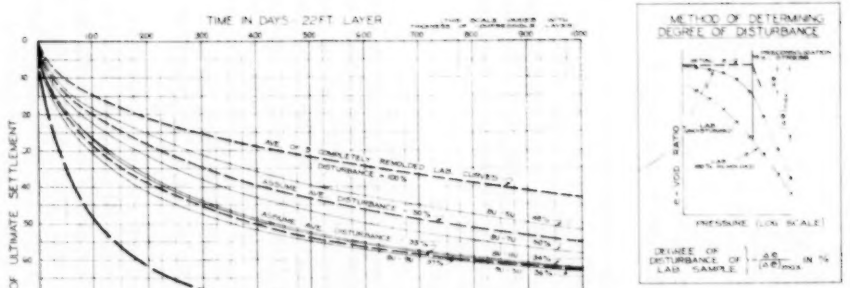
The excellent comparisons between computed and observed settlements indicated in Table I is an example of the successful application of the theoretical concepts that preceded this analysis. It is particularly significant that most of the computed settlement was recompression settlement. Hence, here is an example of the successful computation, by a rational method, of recompression settlements. As shown by this example such settlements can be of very significant magnitude.

The Laboratory Time Curves

The writer has often heard the complaint that laboratory time-consolidation curves gave too slow rates of consolidation when extrapolated to the field conditions. The basis of extrapolation was usually from the height of the test sample to the height of the compressible layer by the conventional square relationship.[7] Any observed discrepancy is generally explained by either assuming the permeability of the soil much greater in the horizontal direction or by assuming two or three dimensional drainage instead of the one-dimensional in the laboratory consolidation test. However, the writer believes that some of the discrepancy may be accounted for by the effects of sample disturbance on the laboratory time curves.

The writer has so far had only one opportunity to check this hypothesis. This was a case of a 5-1/2 million gallon oil tank, 140' in diameter, which was placed on approximately 18' of new granular fill overlying a uniform 22 layer of compressible organic silty clay. Thus here is a case where the extensive fill and large diameter tank over a relatively thin compressible formation insured that the drainage was essentially one-dimensional.

Five undisturbed and two completely remolded consolidation tests were performed on samples from this site. Typical virgin slope time curves from these tests, adjusted by the square relationship for a 22' layer, are plotted with light solid lines on Figure 13. Each test curve was assigned a degree of disturbance determined, as shown, by a method utilizing consolidation test results. Groups of time curves were then assigned average disturbance values, and the completely undisturbed time curve was extrapolated by the method shown.


TIME IN DAYS 22FT. LAYER
PERCENTAGE OF ULTIMATE SETTLEMENT
EXTRAPOLATED UNDISTURBED TIME SETTLEMENT CONSOLIDATION
METHOD OF DETERMINING DEGREE OF DISTURBANCE
e = VOID RATIO
PRESSURE (LOG SCALE)

EXTRAPOLATION OF UNDISTURBED TIME-SETTLEMENT CURVE FROM PARTIALLY DISTURBED LAB. CONSOLIDATION TESTS

FIG. 13

Figure 14 shows the average undisturbed and completely remolded consolidation test results. Utilizing the extrapolated time curve on Figure 13, an average existing effective stress was computed at a specific point under the tank. The average existing void ratio was also computed at this point. The result of these computations was the stress-void ratio point indicated by the heavy cross on Figure 14. This point was assumed to be a point on the field virgin slope. Therefore a true virgin slope was constructed on Figure 14 through this point.

Utilizing the undisturbed time curve on Figure 13 and the undisturbed virgin slope on Figure 14, settlement vs. time computations were made for three points under the tank at which settlements had been recorded. Figure 15 indicates the comparisons of observed and computed time-settlement curves for the three points.

CONCLUSIONS

1. Evidence has been presented which indicates that the geologic virgin and rebound slopes are similar to those observed in laboratory consolidation test results.
2. Alternate methods are available for the important estimate of the preconsolidation profile.
3. It is possible to perform a rational reconstruction to estimate the true pressure-void ratio diagram from the partially disturbed laboratory consolidation test.
4. Construction of the estimated true pressure-void ratio diagram permits the simple computation of recompression as well as virgin consolidation settlement.
5. It may sometimes be necessary to correct the laboratory time curve data for the effects of sample disturbance.
6. In order to minimize any errors involved in the suggested methods of extrapolation, it is desirable to obtain the best possible laboratory "undisturbed" samples.

ACKNOWLEDGMENTS

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The writer also desires to extend his special appreciation to Dr. P. C. Rutledge, Mr. James D. Parsons, and Professor J. O. Osterberg.* These men taught and greatly encouraged the writer to develop the usefulness of the laboratory consolidation test.

The personnel of the Moran, Proctor, Mueser and Rutledge Soil Mechanics Laboratory, under the supervision of Mr. Parsons, are responsible for the completeness and quality of the laboratory data used to illustrate this paper.

Mr. Alex Shayer helped the writer with the preparation of the figures included herein.

*Professor of Civil Engineering, Northwestern University, Evanston, Ill.

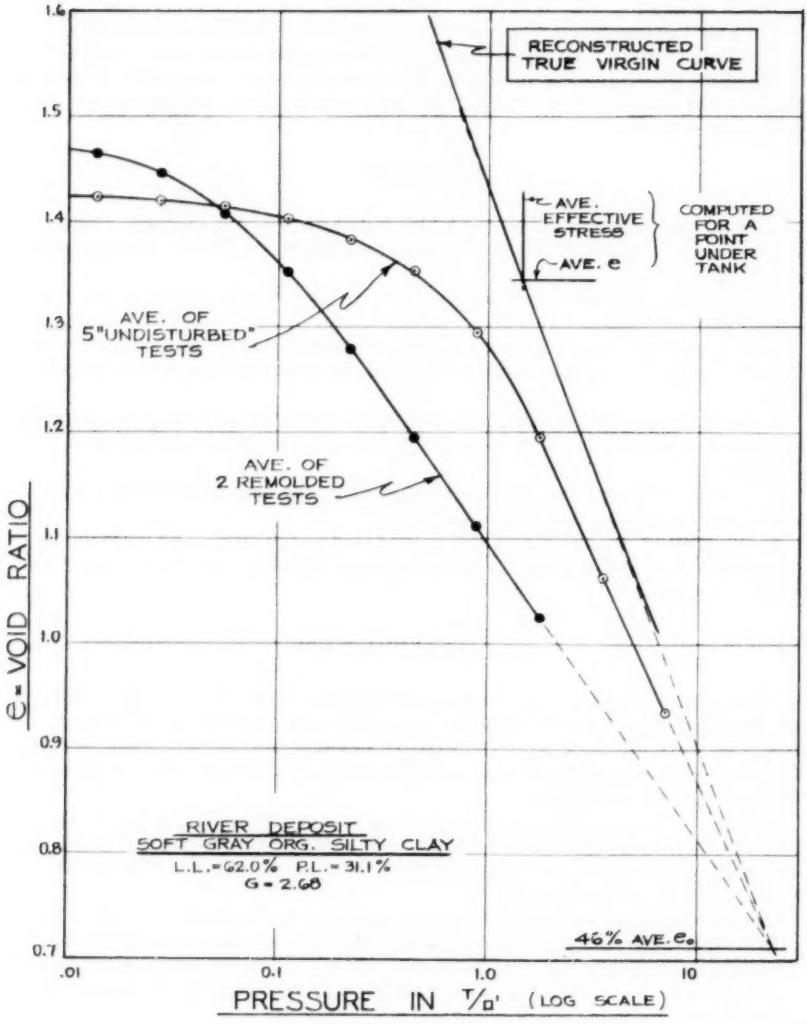

FIG. 14 - DETERMINATION OF TRUE VIRGIN CURVE

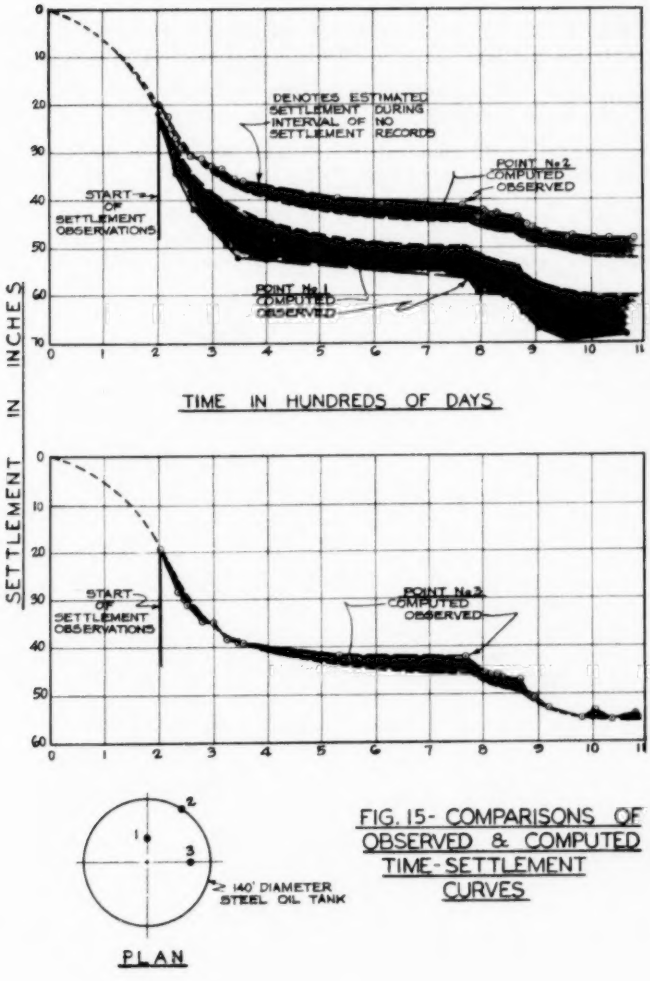

FIG. 15- COMPARISONS OF OBSERVED & COMPUTED TIME-SETTLEMENT CURVES

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